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by

Ge Banjun and Wang Chenglin

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Applications and Development of Global Positioning System

Ge Banjun

(Institute 512, Aerospace Industry Headquarters)

Wang Chenglin

(Beijing University of Aeronautics and Astronautics)

Abstract: This paper presents a general description of the major applications of the Global Positioning System (GPS) in civil and military areas. Also, it proposes some countermeasures and suggestions concerning the applications of the Global Positioning System in China by analyzing the GPS receiver market and its development in the years to come.

Key words: global positioning system, application, development, countermeasures

Featuring global (air, sea and land navigation, positioning and timing), all-weather (free of weather effects) and continuous real-time services, the GPS of navigation satellites can provide various data in timely manner, such as the three-dimensional coordinates and the tracks of test sites, flight declination angles and flight declination distances as well as accurate time information. Subsequently, it has broad application prospects in military and civil areas and virtually has already been applied in many fields.

I. Applications of Global Positioning System

1. Applications of GPS in Navigation

With the selective availability (SA) method, the United States reduced the precision of its civilian-oriented GPS

Standard Positioning Service (SPS) to a 100-meter precision in single-point horizontal positioning. To overcome this weakness, GPS users developed a new positioning technique, i.e. the Differential GPS Positioning Technique (DGPS), which is capable of raising the precision of real-time navigation positioning up to within 1 meter. This method can provide significant technical grounds for accurate navigation positioning of various moving carriers.

The pseudo-range differential real-time navigation technique, used in crop spraying flights, can arrive at a real-time positioning precision of less than 30 meters and can replace the present artificial ground reference navigation method, thus saving large of numbers of personnel, material and funds. This technique has achieved remarkable benefits in aerial spraying against the wheat aphid and successfully passed testing and in the city of Beijing.

Since 1988, the GPS navigation positioning system has been applied in aerial geophysical surveying in China, resulting in saving a huge amount of funds and greatly enhancing the reliability of field data collected for mineral resources and oil-gas prospecting. In the Tarim Basin, GPS navigation has covered over 160,000km in the vast desert; in addition, it has also been employed in aerial surveys of Bohai Bay; Chaidam Basin, Qinghai Province; Inner Mongolia and Ningxia and obtained qualified survey data. The GPS navigation technique has become a major navigation means in aerial geophysical surveys.

As far as civil aviation navigation is concerned, the United States federal Aviation Agency (FAA) worked out a research and testing program in this area. The FAA started implementing a policy of GPS three-stage application. In the first stage, it was announced on June 9, 1993 that GPS could be used in visual flights. In the second stage, after the U. S. Defense Department

declared that GPS possessed initial operation capabilities (IOC), GPS was authorized to replace another long-range navigation system, and it was permitted to apply a single GPS system with receiver automatic intact monitoring capabilities (RAIM) along some short-range marine air routes that required only one long-range navigation means. In such flights, pilots were able to conduct nonprecision instrument approximation using GPS as the major flight guidance tool, without needing to monitor the land-based navigation equipment. During the third stage, the FAA announced on June 8, 1994 that a wide area amplification system (WAAS) was scheduled to be constructed, which, completed in 1997, would allow GPS to perform air route navigation, single navigation with nonprecision approximation as well as first-level precision approximation under DGPS.

Owing to the impact of GPS, the development of the U. S. microwave landing system (MLS) project was suspended, and the FAA will make a final decision on the future of MLS in 1995. MLS might be canceled as long as GPS could meet the CAT-3 performance standard set by the International Civil Aviation Organization (ICAO). The FAA already notified the ICAO that it would cancel its promise to mount MLS in international airports as of January, 1998. Accordingly, the ICAO will hold a meeting in 1995, during which the original decision of taking MLS as an international standard will be reconsidered. The retirement of MLS, once announced by the ICAO, will be a significant turning point in civil aviation navigation, meaning that land-based radio navigation equipment will be discontinued, and satellite navigation will be the major or the only navigation means in civil aviation.

After the U. S. Defense Department declared that GPS had reached initial operation capabilities and the FAA announced the GPS in-stage application arrangements, the ICAO took GPS as a selected part of the civil aviation-oriented global navigation

satellite system (GNSS) and intended to integrate GPS with GLONASS and INMARSAT for building a single civil aviation-oriented navigation system with high reliability, high precision, high built-in capability and global coverage capabilities.

In the area of ship navigation, GPS is capable of providing a wealth of real-time navigation information, including to-port voyage, velocity, course, arrival time and flight declination distances, etc. In addition, the navigation type GPS also has area entry alarming capabilities to prevent ships from entering some special areas like those with submerged reefs, beacons, islands and harbors.

In land transportation, many firms developed a mobile target monitoring and command system. By incorporating satellite positioning and mobile communication as a whole, this system can not only realize automatic positioning of mobile objects, but also provide wireless data and voice transmission in the same system, and display the tracks of mobile objects on the electronic maps through computer in the control center. Additionally, this system can be used for monitoring the progress of significant motorcades or vehicles, performing accurate positioning of special targets, tracking and protecting vehicles carrying important documents, materials and money, and monitoring luxury cars to prevent them from being stolen or robbed. Systems of this kind are being widely applied in other countries of the world. In China, a GPS vehicle monitoring and dispatching system, developed by Huacheng Satellite Communications Company, the Science and Technology Development Corporation under Northwest Industrial University, Dahen Company and Wuhan Mapping Science and Technology University, has advanced to the practical stage and has been employed in public security vehicle dispatching, bank vehicle monitoring, etc., and achieved satisfactory benefits. Application of GPS in vehicle management and navigation appears to be the trend and a tide in world

vehicle management, and China serves as a tremendous market in this regard.

2. Application of GPS in Positioning

(1) Application of GPS in Geodetic Surveys

The classical geodetic survey is aimed at determining the two-dimensional positions of survey stations by building a plane control network through triangulation and traverse survey as well as constructing an altitude control network through level gauge surveys. This method, severely constrained by atmospheric and topographic conditions, suffers from high labor intensity, high cost and low efficiency. With the advent of GPS, however, the geodetic survey method underwent a thorough revolution to generate a new technical subject--GPS Geodesy. With GPS signal receivers of survey type, the three-dimensional coordinates of survey sites can be derived at any time and in any place across the world without requiring interstation sighting and construction of surveyor beacons, or independent realization of altitude surveys and plane control.

The International Geodesy Association built a global GPS geodynamics service (International GPS Geodynamics Service--IGS) observation network and established GPS fixed observation stations in Europe, Asia, America, Oceania and on some related islands in the Atlantic Ocean, Indian Ocean and Pacific Ocean. This network is intended for studying the Earth's rotation and orientation, monitoring geotectonic movement and crustal deformation, monitoring global sea level fluctuation and constructing precise global earth coordinates. Through long-term observations of the fixed locations of individual continental plates, this network is able to confirm how many centimeters a year the plates displace against each other, which can provide indisputable evidence for the continental drift--plate tectonics

theory in the field of geology. GPS has been applied in geodesy for only approximately 10 years in China, yet it has been developed rapidly and now continues at a booming stage.

As far as the global network is concerned, our four stations located respectively in Beijing, Shanghai, Wuhan and Nanjing were connected to the global observation network and in 1992, they joined the '92 IGS mass campaign organized by IGS. During this period, they carried out observations on 15 consecutive days and obtained accurate geocentric coordinates of all the above stations and also provided IGS with reliable data.

In the nationwide network, the Mapping Bureau under the Headquarters of the General Staff built a national GPS first level network of 44 observation sites in 1992; the State Mapping Bureau started constructing a national GPS space positioning network of 694 observation sites in 1992. As regional geodetic control networks, area or region control networks were built in Northwest China, North China, Beijing and Tianjing, Zhujiangkou and Nanhai. In addition, city control networks were set up in Tianjing, Beijing, Fushun, Yangzhou, Shanghai and Chongqing, which reached centimeter level precision for point surveys, while the cost was only 1/3 of the conventional method but the speed was 6 times faster. The City and Village Construction Committee provided that the future reform of the control networks in 400 cities of the nation will be made by using GPS. Also, GPS was applied in the survey and control of other engineering projects, such as tunnels, airports, mines, coal fields, subways and water conservation, resulting in saving time and raising positioning precision.

(2) Application of GPS in Earthquake Monitoring and Disaster Prevention and Relief

Predicting large earthquakes by monitoring the variation of the crustal movement, crustal deformation fields and stress

fields with GPS technology has become a new earthquake forecast technique. This advanced technique has been incorporated in national development planning in the United States, Japan and Canada.

The United States has built an A-level GPS observation network with 65 observation sites and is now constructing another network of this kind at B-level with 2500 observation sites. Mobile observation networks have been densely deployed on the well-known seismic zone--Saint Anders fault zone, and a GPS observation network with over 200 observation sites is being planned to cover the key monitoring sections. In Japan, a GPS fixed monitoring network with 16 observation stations was built in the Capital zone which successfully monitored the seismic activities east of Yi Dong Peninsula in mid June 1989, and the crustal deformation prior to the Teishi volcano eruption, demonstrating the efficiency and applicability of GPS technology in monitoring crustal deformation as a prelude to an earthquake or volcanic eruption. The Territory Geography Academy is planning to extend the GPS fixed monitoring network in two reinforced seismic observation regions--the Donghai and South Guandong by setting up 200 GPS fixed monitoring stations. The University of Tokyo and University of Jingdu also will establish three GPS monitoring networks in the volcanic regions in the eastern part and southern part of Japan specially for earthquake monitoring research. Following the large Osaka-Shen Hu earthquake on January 17, 1995, Japan sped up the construction of satellite earthquake-monitoring systems. In Canada, a GPS monitoring network was built in Vancouver, which was designed to regularly survey the temporal and spatial variations of plate movements and crustal stress fields, as well as to study the relationship between earthquakes and crustal deformation and to explore the issue of earthquake forecasting.

Seismic activities on the mainland of China, quiet for

nearly 20 years, has now entered a new active period. The State Seismic Bureau is planning to formulate initially a large earthquake monitoring system, earthquake damage prediction and earthquake catastrophe quick evaluation systems and a satellite communications system by the year 2000, using GPS technology along with remote sensing technology and geographic information system technology. This program involves: (1) constructing a nationwide GPS earthquake-monitoring network with 150 monitoring sites; (2) establishing GPS earthquake-monitoring networks in the major earthquake-monitoring regions of the nation and (3) building a Capital zone GPS fixed monitoring network with 50 monitoring sites. At present, the earthquake-monitoring networks in North China region and Capital zone are under construction.

GPS can also plays an important part in monitoring and preventing other catastrophes, including monitoring the warning indications for deformations of large dams, ground subsidence and landslides.

3. Application of GPS in Space

GPS has wide application prospects in area of space, such as navigation and positioning of spacecraft, flight track determination, landing operations and satellite tracking.

The simulation research of precise track determination, conducted in the United States with GPS in the TOPEX/Poseidon satellite, demonstrates that DGPS technology can meet the requirements of accurate marine satellite track determination with an altitude error within 5cm. The Landsat-5 launched in March, 1984 carried GPS on board. The United States GPS Unified Planning Agency is scheduling development of a universal spacecraft and GPS receiving system, which is supposed to possess the capabilities of automatic track sidereal determination and automatic attitude determination. With these superiorities, this

system can greatly relieve the ground tracking orbit-determining network. Linking the air-borne or satellite-borne remote sensors to GPS receivers will be a direction in developing future space remote sensing technology (RS). It will be able to provide remote sensing images with precision space coordinates for users and make it possible for remote sensing data to directly enter the geographic information system. With this a scenario, GPS, RS and GIS will be combined organically to form a new generation remote sensing applied technology system.

4. Application of GPS in Astronomical Systems

In China, the time and frequency system is the first astronomical system that was involved in GPS area. The GPS transmitted accurate time scale is convenient for comparing the atomic time of China with the atomic time of the world, as well as comparing different atomic time references of China. With Shaanxi Astronomical Observatory of the Chinese Academy of Sciences as a center, a comprehensive atomic clock for China was started up, which, through the time service system of Shaanxi Astronomical Observatory, can provide time and frequency service across the country. The accurate double-frequency GPS receiver can offer accurate coordinate location of survey sites and can basically eliminate the refraction effect of ionosphere, thus greatly raising the precision of the comprehensive atomic time.

By measuring the total electron content (TEC) of the ionosphere with the GPS satellites, the continuous variation of the ionosphere can be measured, and the law of TEC activity can be studied, which can provide ionosphere variation data for telecommunications, navigation and surveying.

5. Application of GPS in the Military

The original purpose of designing the GPS system was to

serve the military. The military requires high precision code (P code), which allows a positioning precision within 10 meters. In the Gulf War, the efficiency of GPS was brought to a full play.

In the Gulf War, GPS served as an indispensable positioning equipment in Allied forces for lack of ground references in the Southwest Asia desert. Military-oriented GPS receivers were delivered to almost all the combat troops. The number of various GPS receivers used in the war was approximately 17,000. The U. S. Air Force equipped 251 F-16A/C fighters with such receivers aimed at implementing an attack on strategic targets, controlling areas of space, intercepting enemy aircraft and providing short-distance support, etc.

The total number of sorties carried out was more than 13,400 with only 5 lost, i.e. the decisive victory of the war was won at a very small cost. In the beginning of the war, the U. S. Air Force launched against Iraq altogether 35 AGE-800C cruise missiles with GPS composite guidance, turning a regional target attack into a point target hit. As a result, the missiles accurately hit the preset bombing sites and severely damaged the well defended Iraqi power plants, transmission stations and military communication facilities. This was the first big contribution that GPS made while applied in the war.

During and after the war, GPS was used to sweep mines in sea areas and provided battlefield mine-sweeping positioning with a precision high enough to obtain accurate data of the swept areas. On the battlefield, it swept 1,750,000 mines and bombs and created a miracle in battlefield clearing.

The application of GPS in the Gulf War indicates that GPS is an efficient multiplier of operating weapons and vital technical support in winning a war. The U. S. Senate Military Commission expressly provided that from the year 2000 on, aircraft,

warships, armored vehicles and indirectly launched weapons will no longer get upgrade and purchase funds if not equipped with GPS receivers.

The U. S. Army has confirmed 64,000 potential users and are planning to purchase 3500 GPS receivers. The army units which use GPS receivers include the special units, mapping, intelligence, electronic warfare, transportation, artillery and air forces. The special units and mapping units employ GPS receivers for positioning and telling the way, while ground units and air defense artillery units--for accurate positioning and controlling the fire control equipment. The U. S. Navy is mainly equipped with 5-channel GPS receivers aiming at warship navigation and making corrections to link coordinate barriers. According to the estimates by the U. S. Defense Department, American armed forces will possess 100,000 sets of actual combat-oriented GPS receivers by the year 2000.

Apart from the U. S. military, other countries must sign a memorandum with the U. S. government before employing military-oriented GPS. The memorandum states that the user country cannot provide the P code receivers to a third country unless approved by the U. S. Defense Department. So far, North Atlantic Treaty countries, Australia and Canada have such approval, and Japan will soon sign a "Safety and Obligation" memorandum with the U. S. Defense Department for its Air Force and Navy, who intend to purchase 2000 P code military-oriented GPS receivers. Additionally, the Netherlands and Norway are developing military-oriented GPS receivers for civil use, which are to be used by warships and armed forces.

The above analysis is devoted to the major military and civil applications of GPS. Also, GPS plays its role in other fields, including field expeditions, archaeology, wild animal protection and monitoring, power line breakdown positioning, etc.

In short, GPS can be used for timely and accurate determination of location and time wherever it is needed: from space to underground, from land to ocean, from city to wilderness, from motionlessness to motion. GPS will surely spread to every area of human activity, from production, everyday life, new world order, to space exploration and development.

II. GPS Receiver Market and Its Development

With the application of GPS technology in an ever increasing number of businesses, the demand for GPS receivers has been growing rapidly. Statistics made in January, 1994 show that there are 59 manufacturers in the world, which are engaged in producing 315 kinds of GPS receivers for use in sea, land and air surveys. It is estimated that by the end of this century, the number of GPS users will reach approximately 500,000 in the United States alone, and over 100,000 people will be involved in GPS industrial production with an output value of more than $5 billion.

GPS receivers will be developed which are smaller and smaller in volume, more and more powerful in function, more and more lightweight, more and more perfect in data processing software, with wider and wider applications but lower and lower in price. In China, GPS has only been applied only for 10 years, yet it has already displayed its highly productive force in national economic construction. The demand for GPS receivers is growing increasingly in some related production areas.

Aware of the huge demand on the Chinese market, some large foreign GPS receiver companies have entered products on the market one after another in the past few years. At present, among the foreign companies and manufacturers engaged in GPS receiver sales in China are: the American Trimble Navigation Company, Ashitech Company, Rockwell Company, Magellan Company,

GARMIN Company, EAGLE Company; French SERCEL Company; Swiss Leica Company, etc.

Apart from selling GPS receivers in China, these companies constantly offer GPS technology lectures to Chinese users, organize new product shows and establish Chinese user associations under individual companies and regularly or irregularly distribute GPS application bulletins or correspondence. All these measures can help Chinese users better understand the GPS technology, extend application scope and raise the degree of application and more importantly, enlarge their sales market and earn high profit.

On the other hand, our own ability of producing GPS receivers is still very weak. Only a few departments including Institute 704 of Aerospace Industry Headquarters can manufacture navigation GPS receivers, but not series products, and so domestic products have not yet made an impact. Therefore, our domestic market is still dominated by foreign products.

Looking forward, with further development GPS technology is likely to be as popular as color TV sets and videos. With regard to such an enormous market, our government should work out an appropriate policy to produce GPS products which are capable of competing with foreign products in quality, performance and cost; otherwise, our domestic market will be lost.

At present, corresponding management measures should be taken in GPS receiver domestic sales, which are aimed at encouraging domestic products. Under the present relatively backward technological level, it is wise to import, at the expense of part of the market resources, sophisticated GPS receiver production techniques and necessary element devices so as to make our domestic GPS receivers keep up with the world level. In the meantime, development of new generation GPS

receivers should be placed on the agenda, urgently digesting and absorbing foreign advanced technology so that domestic GPS receivers could occupy a certain portion of the market.

III. Policies and Suggestions to GPS Applications in China

The U. S. Defense Department's general policy toward GPS applications is: (1) Its standard positioning service (SPS) is open to the whole world for civil use, and direct user fee is not charged in civil use from 1993 through 2003; (2) Under the United States national security, SPS precision will be reduced to a certain degree by using selective availability (SA) and (3) From December 8, 1993 (when Defense Department declared that GPS reached the initial operation state), signals would no longer be interrupted or changed; as for some planned or foreseeable interruptions, a 48-hour notice would be made known to user groups through the Coast Guard and the Federal Aviation Agency.

With the American GPS policy, what should our country do in the development of space positioning technology?

1. Grasp opportunities and actively develop GPS civil applications

From 1993 through 2003 is the ten year period GPS is open and also a critical period of economic construction in China. We must grasp this opportunity and make full use of GPS in these ten years so as to improve the people's living conditions by bringing the GPS high precision and cost-efficiency superiority into full play. As far as civil aviation is concerned, since the U. S. FAA decided to stop constructing MLS and place the focus of navigation systems on the development of GPS, and the ICAO incorporated GPS navigation as part of the global satellite navigation system (GNSS), our civil aviation department should join GNSS of ICAO on one hand, and actively develop research and testing on GPS applications in navigation and approximation on

the other, so as to keep up with the world pace, which is particularly important to international flights.

2. Establish a national differential navigation positioning system under unified organization

Since the United States has implemented the SA policy toward civil users, the GPS single-spot positioning precision is no better than 100 meters, while DGPS serves as an efficient measure to raise the positioning precision and overcome the SA interference. So far, DGPS has raised the real-time navigation precision up to within 1 meter and can offer navigation service for ship voyages, port entry and exit. Also, it can provide positioning service for various meter-level precision ground and marine surveys and other services, including airport navigation, automatic railway management, highway transportation management and control, vehicle monitoring, etc.

Some navigation users in our country imported independent DGPS systems to meet their respective needs. However, with large investments, these systems have a limited usage scope and more than this, different systems use different frequencies and thereby cannot be linked with one another, resulting in wasting their superior capabilities and low economic benefit.

With this scenario, it is necessary for the nation to start unified planning for the construction of DGPS systems, under which ground control stations should be built in a unified way across the country. By using international frequency standards and radio data communication standard (RDS), these stations can form a nationwide network through the broadcasting stations all over the country, or deliver differential signals to users in any place of the country through a special channel of the communication satellite. This way, a set of differential navigation positioning systems based on the international standard frequency can be formed, which can ensure GPS precision

in use and increase its cost-efficiency and economic benefits. Under the present conditions, regional DGPS networks can be constructed first in the well developed coastal regions and gradually spread to the entire nation afterwards.

3. Make full use of existing satellite navigation positioning systems and develop satellite positioning signal compatible receivers

The GPS system is a military-oriented system controlled by U. S. military, and if it is not available for civil use when a war breaks out or the ten years terminate, civil users will suffer from a huge loss. In this case, some international organizations and users are considering developing compatible receivers which are capable of receiving both GPS and Russian GLONASS signals simultaneously so that the continuity of positioning information acquisition can be guaranteed, which is even more important for civil aviation users. Study shows that using a combination of two systems is technically possible.

4. Carry out coordinative work among users and bring superiority of group users to full play

The GPS users in China are concentrated in businesses including mapping, petroleum, geology, seismology, coal, transportation and architectural planning. These users, through practice, have come to realize that it is difficult to obtain satisfactory benefits either in efficiency or results in relying on individual businesses alone, and that the only way to bring the receivers into full play is to bring together the limited number of existing receivers and coordinate their use, i.e. learn from the strong points of others to offset one's weaknesses. Ten years ago, a "China Land and Marine satellite Positioning Network Coordination Committee" was spontaneously organized by the users from Wuhan Mapping Science and Technology University, Ministry of Petroleum, State Seismology Bureau and Oil Geophysics Bureau under the Ministry of Geology. This organization achieved great

achievements in the beginning stage of GPS applications in China and was renamed "China Satellite Positioning Technology Coordination Committee" at the end of 1994 with the development of this technology. By December 8, 1994, the membership of the committee enlarged to 70. In the 10 years of effort, remarkable achievements were made in hardware imports, software development and coordinative production. In July of 1992, a '92GPS mass campaign was organized, which involved a large number of departments and units to display unity and a spirit of cooperation. During the campaign, large amounts of observation data were acquired, and a China GPS A-level network was established. In the end of 1994, the State Mapping Bureau headed a preparatory committee intended for constructing a "China GPS Technology Application Association", aimed at increasing GPS technological level, application levels and management levels to promote the development of GPS technology in China.

Based on this foundation, the department concerned of our country should invest more funds on GPS applications and organize all possible forces in tackling the key problems so as to speed up the development of the satellite positioning technology in our country.

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